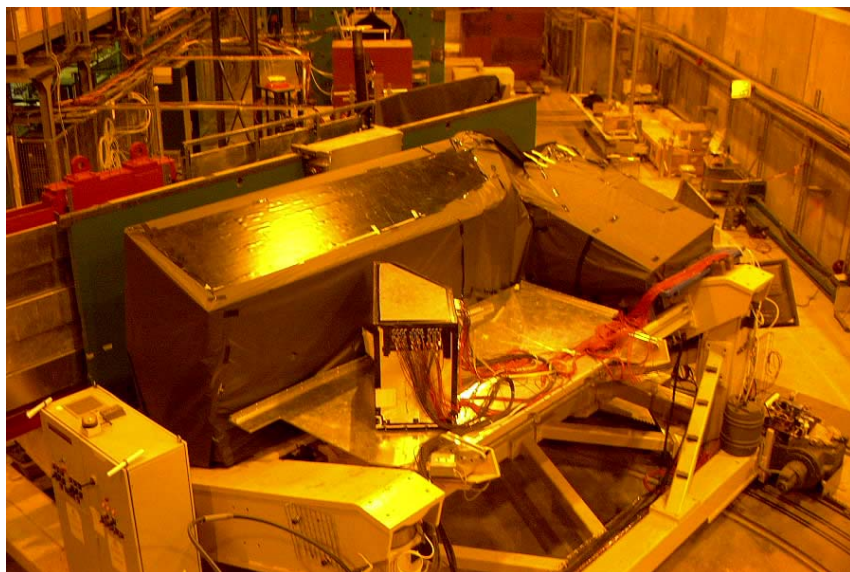




# Results from HCAL TB2004 & Implication to TB2006

S.Kunori  
21-June-2005



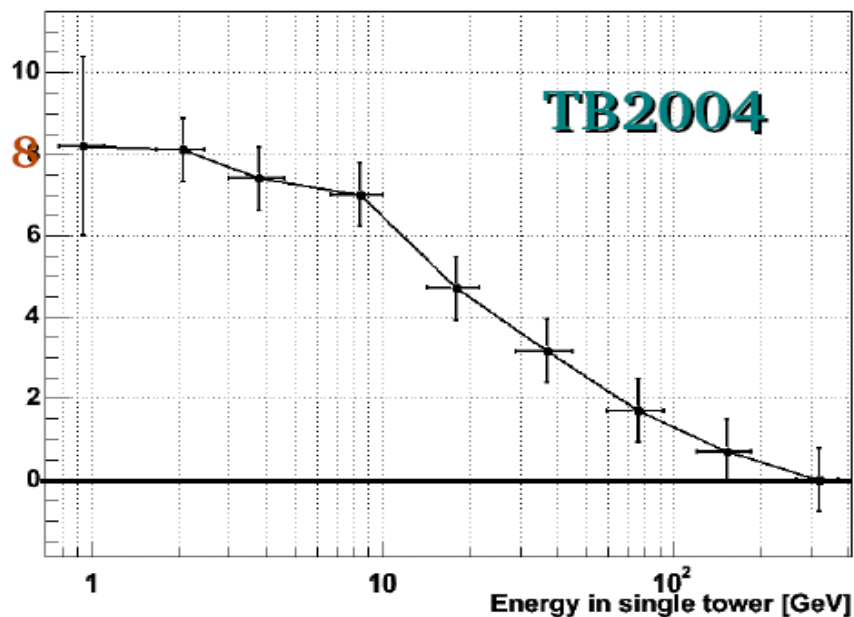
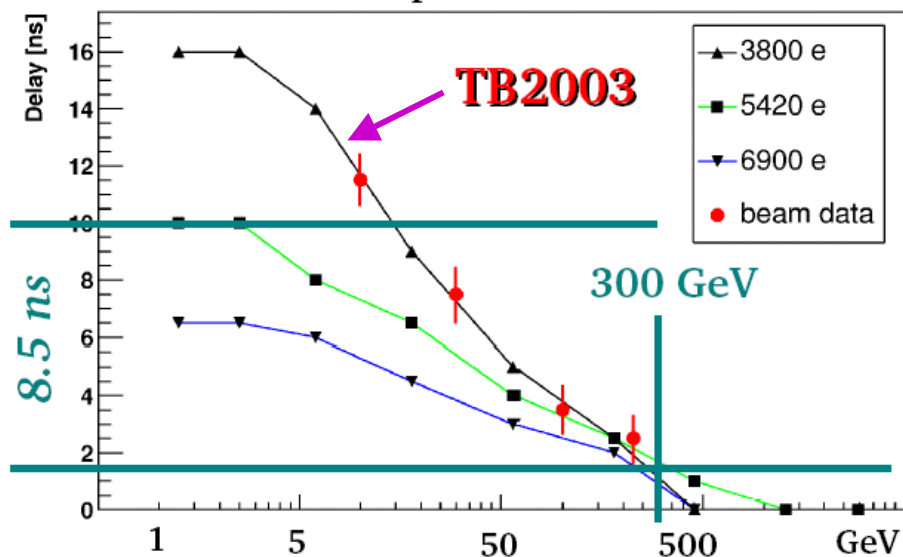


# HCAL Testbeam Program

- 2002**      **HB – Production wedges(2). Production megatiles.**  
Electronics - pre-production, e.g. QIE @33MHz
- 2003**      **HB – PPP1, PPP2**  
**HE – prototype wedge, Production megatiles**  
**HO – Production megatiles**  
**HF – production wedges (2) - limited data sets -**  
**Electronics – production system (most of them)**  
**Synchronization test with 25nsec beam**
- 2004**      **HB – PPP1, PPP2**  
**HE – prototype wedge, PP megatile.**  
**HO – production megatiles.**  
**HF – Production wedges (6)**  
**Low energy beam / TPG (trigger primitive generation)**  
**Slice test with ME.**
- 2005**      **slice test / cosmic test / magnet test (early 2006)**
- 2006**      **HB – PPP1, PPP2**  
**ECAL – a super module or modules**  
**Low energy beam**

# Time Slew

On chip measurement

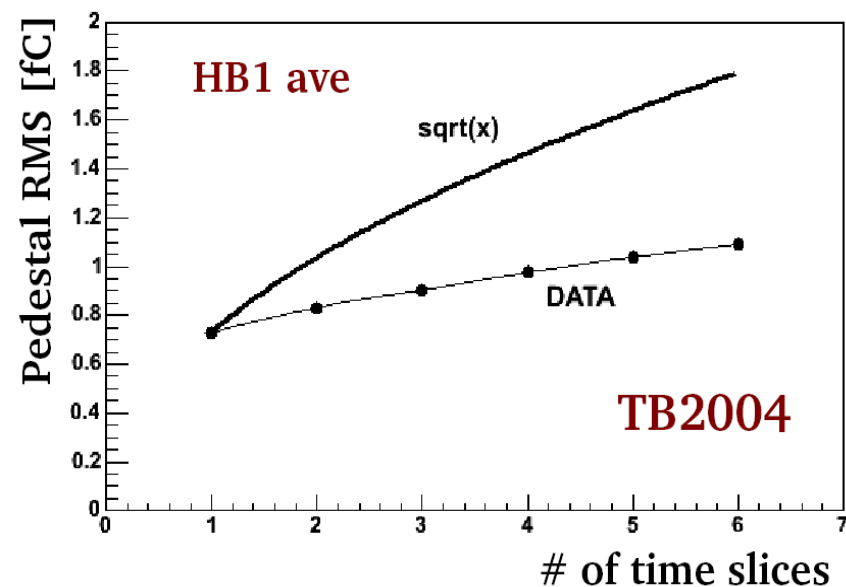


## Original QIE vs New QIE

Original – quiet (for HO)  
New – faster (for HB, HE)

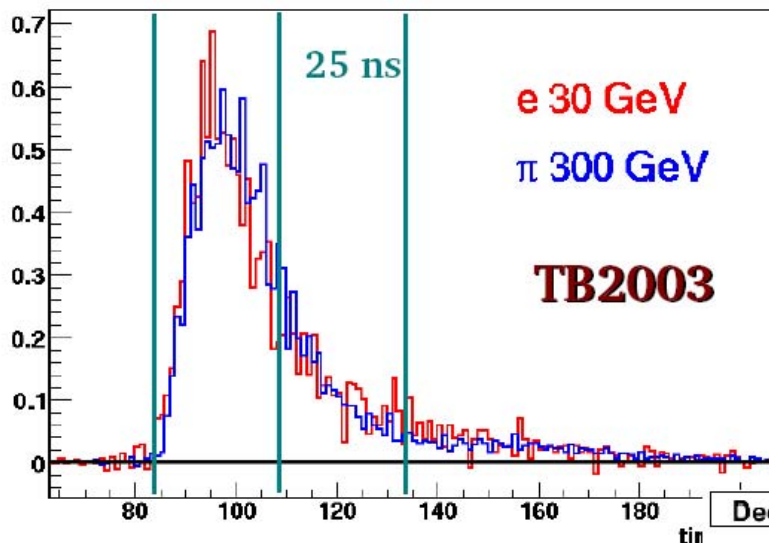
## Noise Level

ped. RMS (1 ts.)  
TB2004: 0.730 fC  
TB2003: 0.586 fC





# QIE Pulse Shape: New vs Old



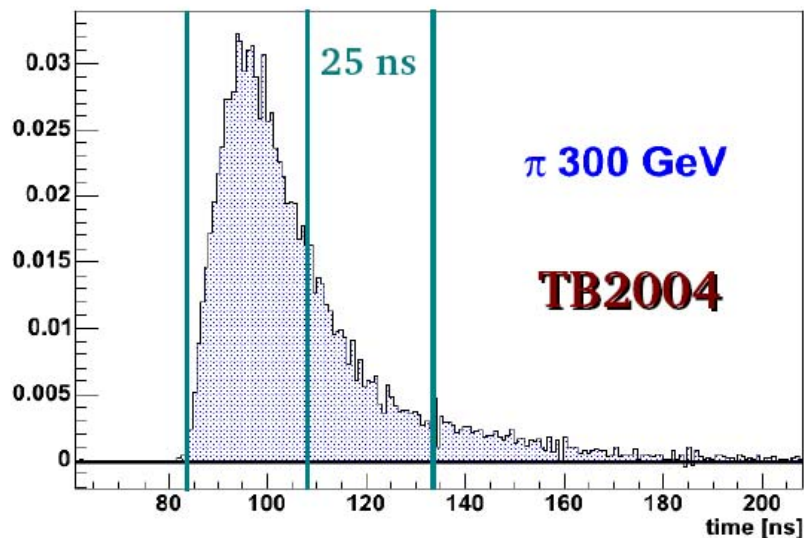
Comparison of the pulse shape with “new” and “old” QIEs.

$$\eta = 7$$

No significant difference in the QIE pulse shape .

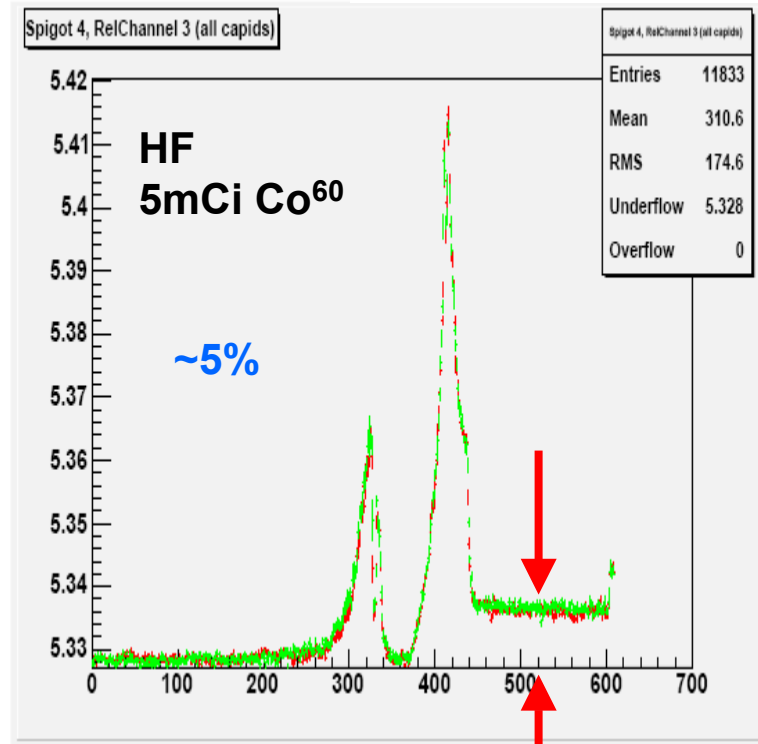
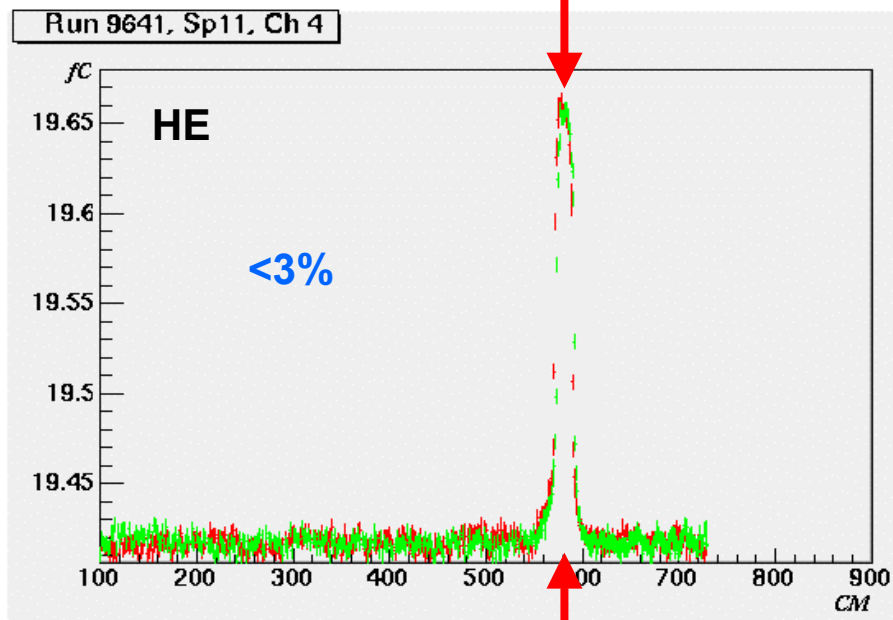
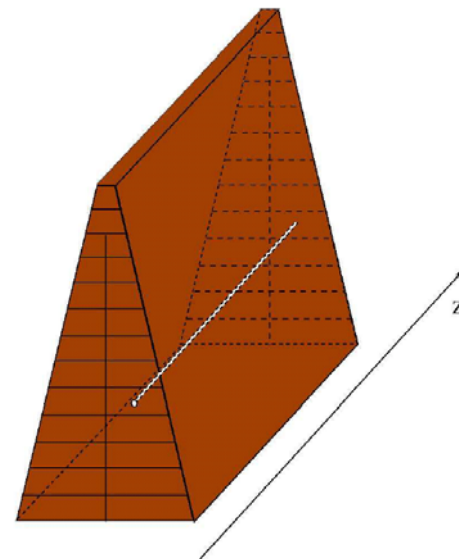
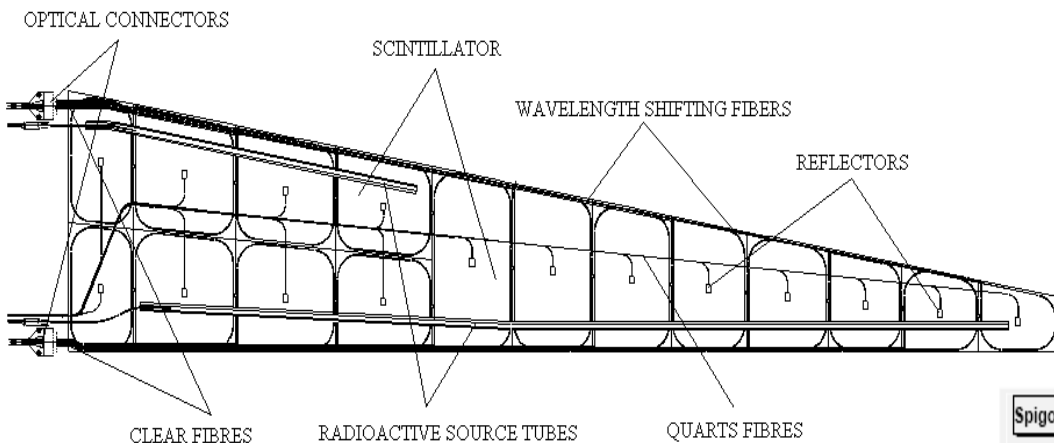
88% signal collection  
In 2 time slices.

Deconvoluted Pulse Shape (25->0.78125 ns)



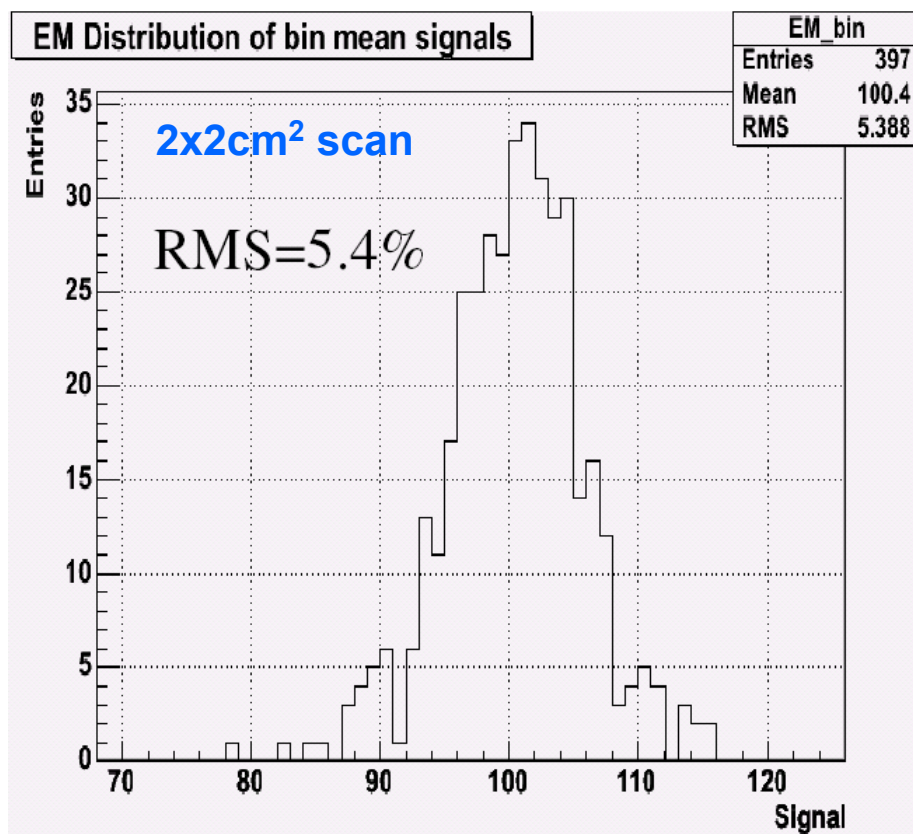
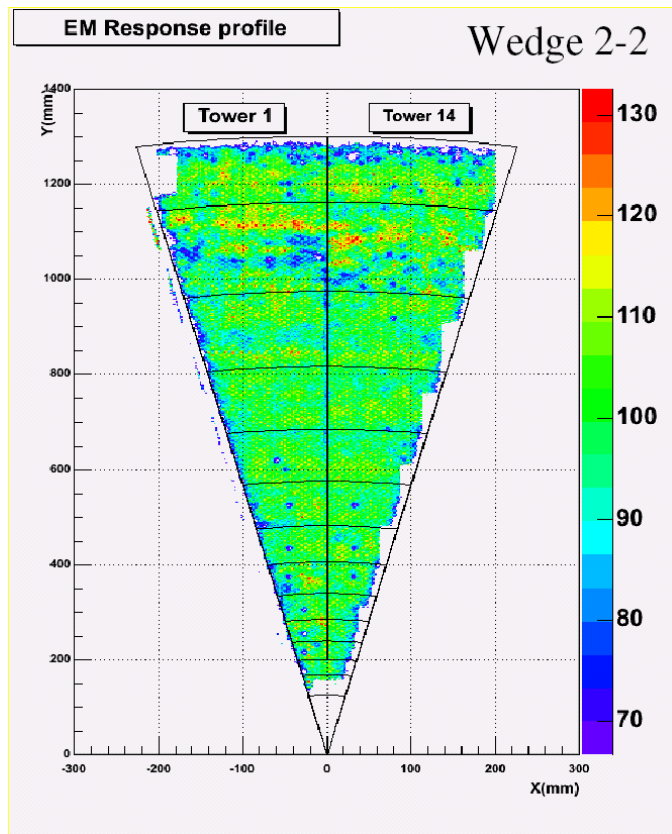


# Wire Source Calibration





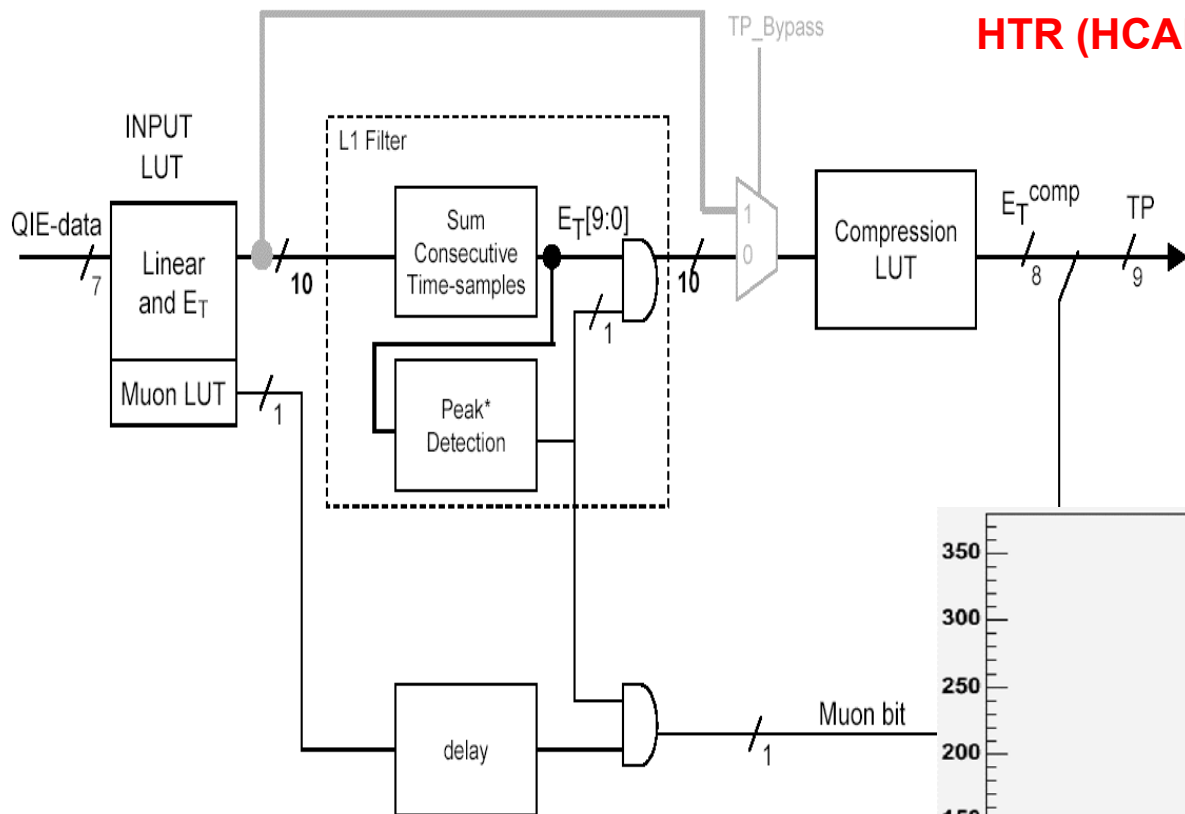
# HF Uniformity



Variations (RMS) of the average response over the HF surface at a medium scale (2cm) are ~5% for electrons and ~3% for pions which contribute to the constant term in the energy resolution for single particles.

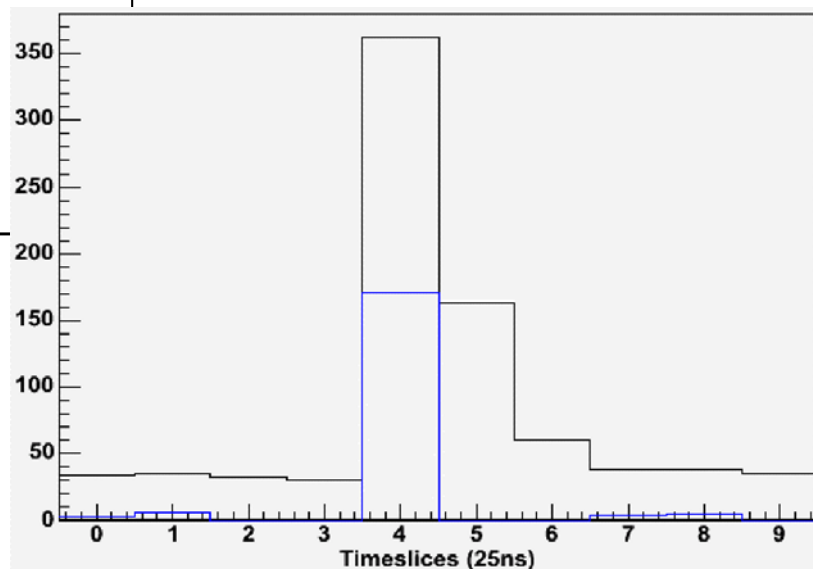


# Trigger Primitive Generation



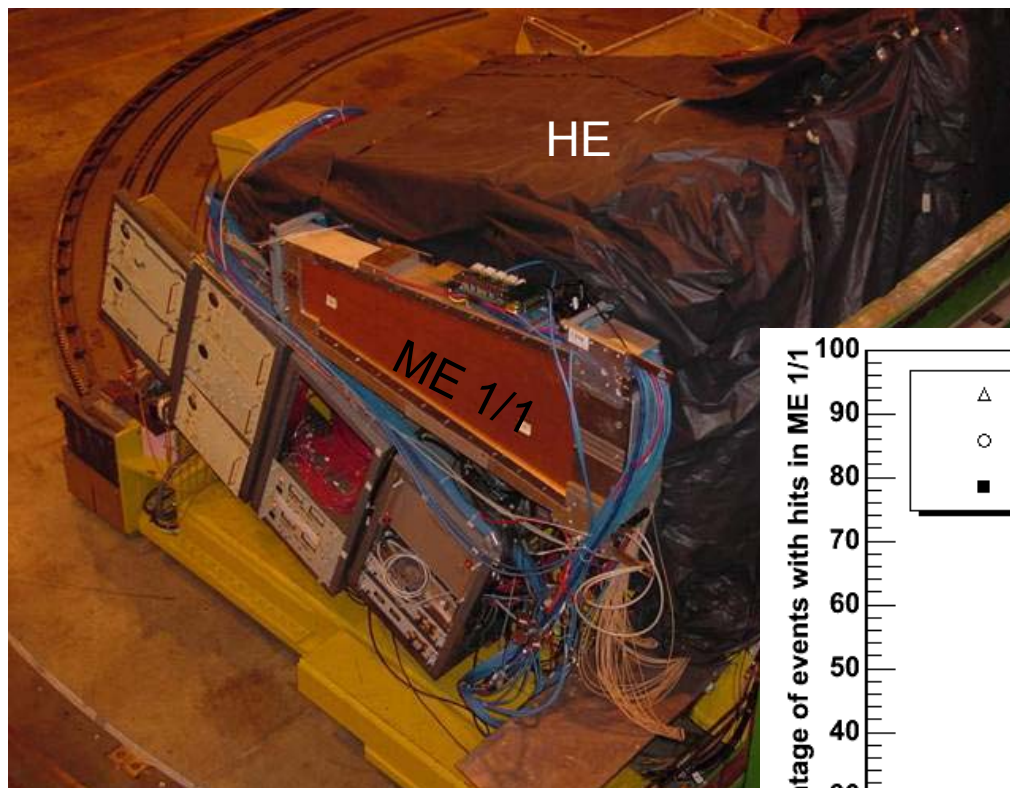
**HTR (HCAL Trigger & Readout)**

**150 GeV pion  
HE with minimal  $\sin(\theta)$   
dependency in LUTs  
(Run #23904- 25ns beam)**

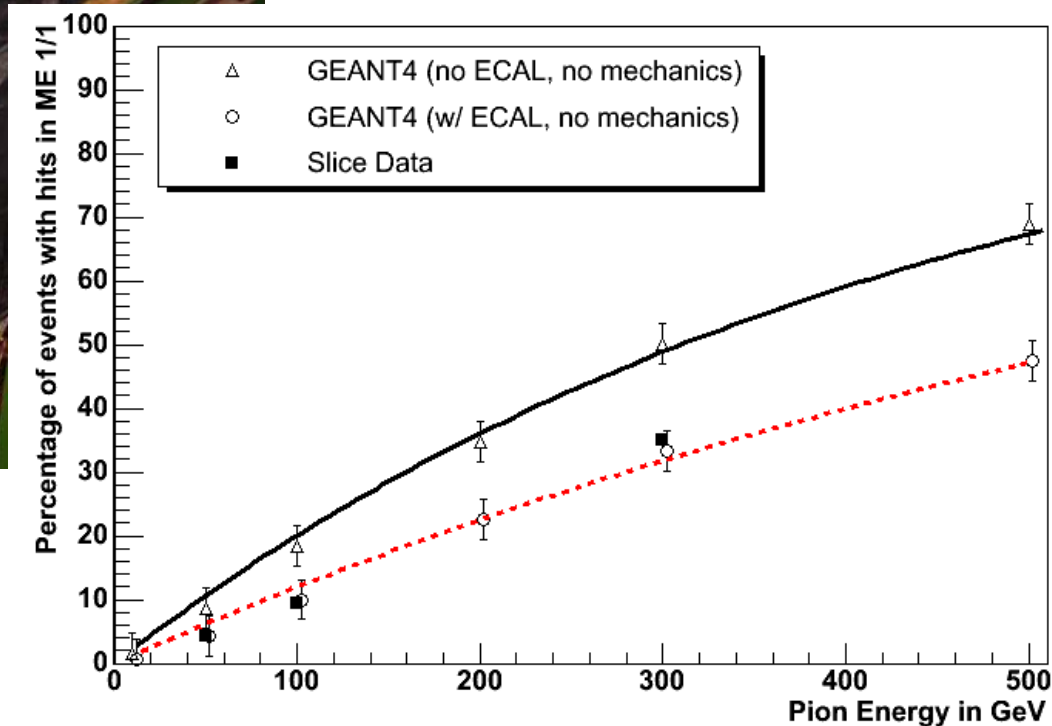




# Slice Test: EE-HE-ME



Punch Through



**Readout from HE and EE were successfully synchronized!**



# GEANT4 Validation Data

## Quantities:

$\pi/e$

Shape of  $dN/dE$  dist.  
(resolution)

Shower profile  
longitudinal  
transverse

## Detectors:

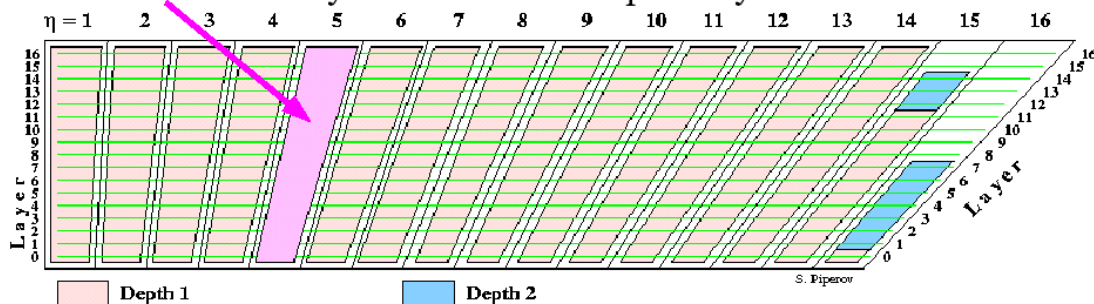
HF:

Cerenkov based

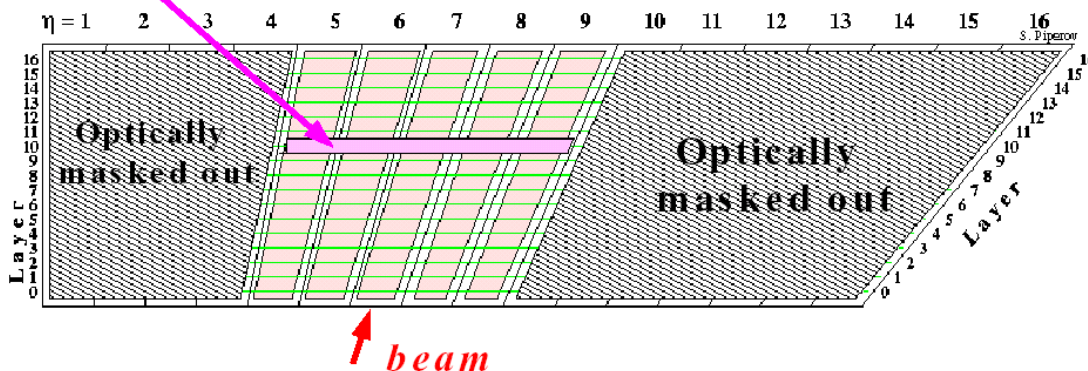
EC+HB

Scintillation based

**HB1:** tower like – layers summed optically



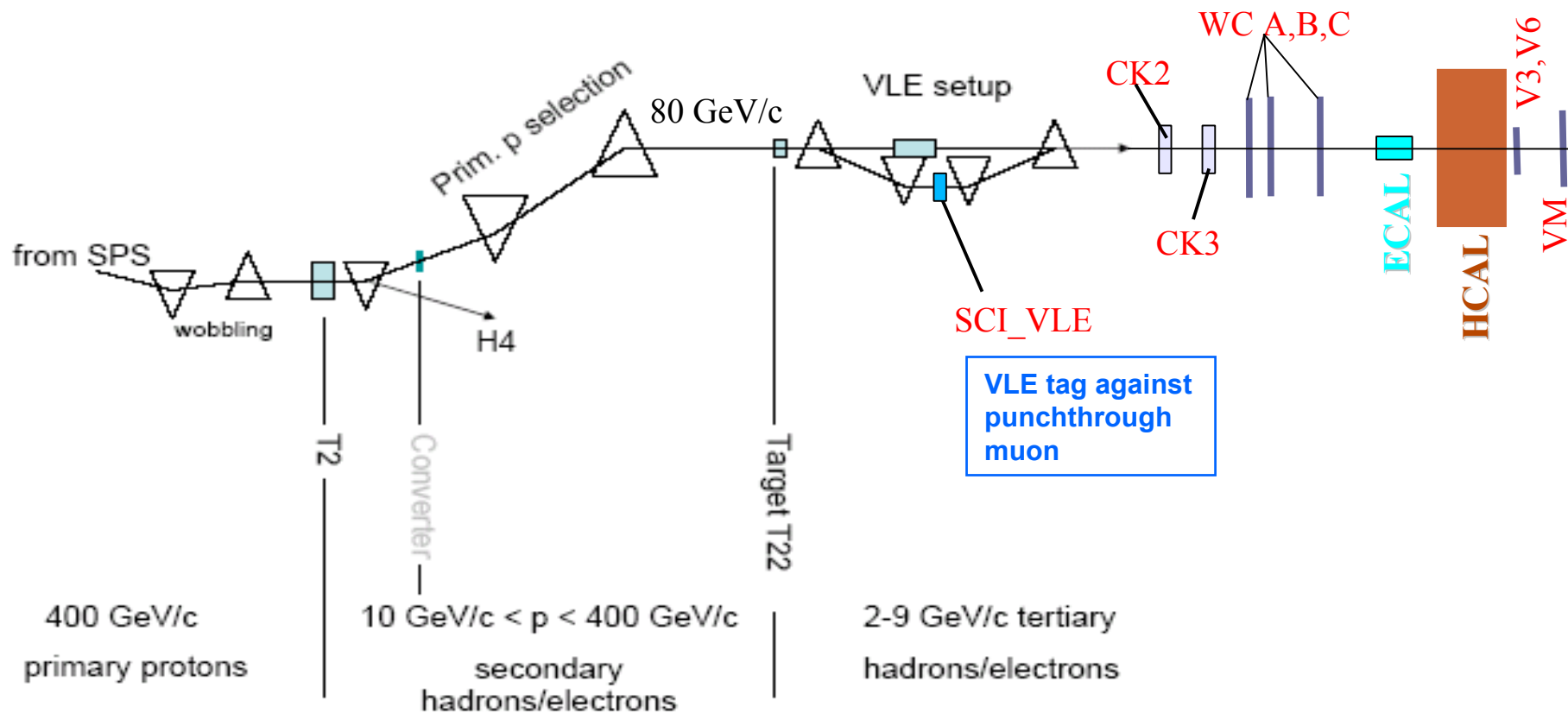
**HB2:** layer like – longitudinal shower profile



HB2 readout was reconfigured for longitudinal shower profile study.



# VLE Beam Line at H2



**P-ID:**

CK2- electron

CK3- pion / kaon / proton

V3, V6, VM – muon

**WC**

single hit to reject interaction in beam line



# Data Sets

## HB runs

- Very Low Energies (VLE)
  - 2,3,5,7,9 GeV mainly  $\pi^\pm$  beam
  - with/without ECAL
  - HB1/HB2
  - Full particle identification
- Medium Energies (MED)
  - 10,15,20 GeV  $e^\pm, \pi^\pm$  beam
  - with/without ECAL
  - HB1/HB2
  - Partial particle identification
- High Energies (HIGH)
  - 30,50,100,150,300 GeV  $e^\pm, \pi^\pm, p$  beam
  - with/without ECAL
  - HB1/HB2

## HF runs

- 30,50,100,150,300  $\pi^\pm$  beam
- 30,50,100,150 GeV  $e^\pm$  beam

**Electron: 5-150GeV**

**Pion: 5-300 GeV**

**Proton: 5-9 GeV**

(2GeV and 3GeV data exist, but a lot of junk.)



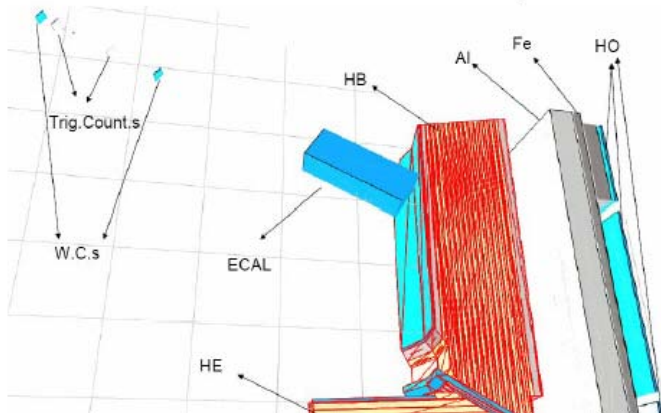
# GEANT4 Simulation

Physics Lists:

- LHEP: **LEP/HEP** *parametrized* models for inelastic scattering.
- QGSP: **Q**uark **G**luon **S**tring model for the 'Punch-through' interactions.
- QGSC: QGSP + **C**hiral invariant phase-space decay.
- FTFP: diffractive string excitation similar to that in FRITJOF and Lund.

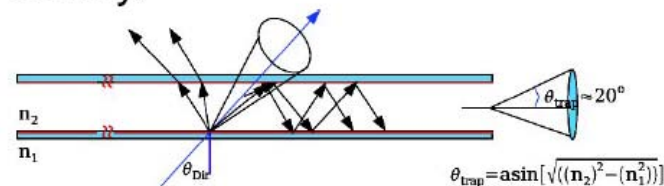
HB simulation:

standard OSCAR TBHcal04 application with minor additions to store information about the first interaction point.



HF simulation:

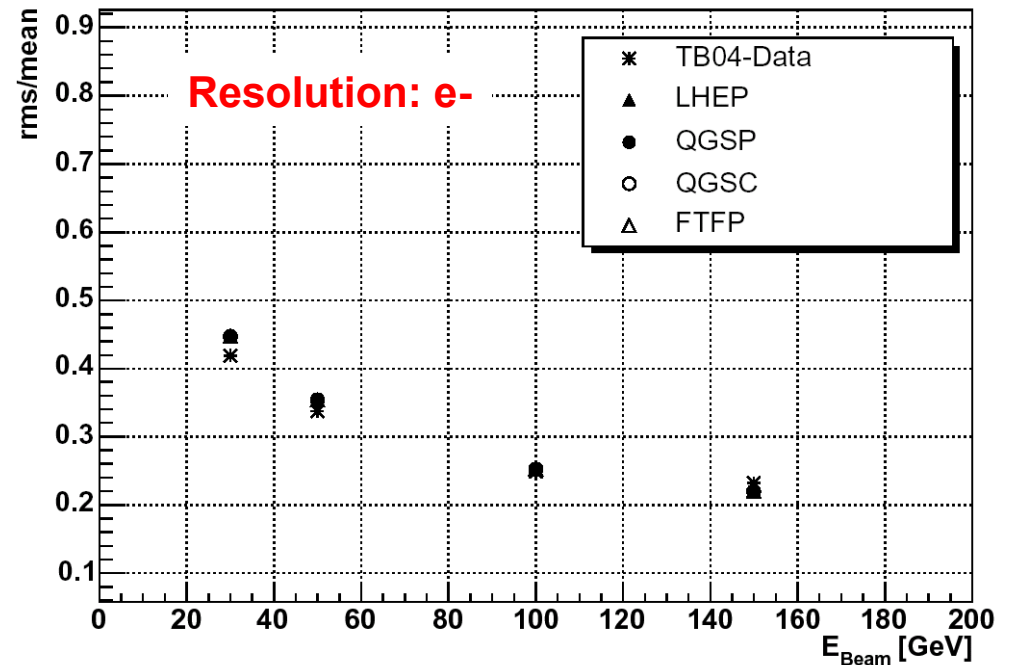
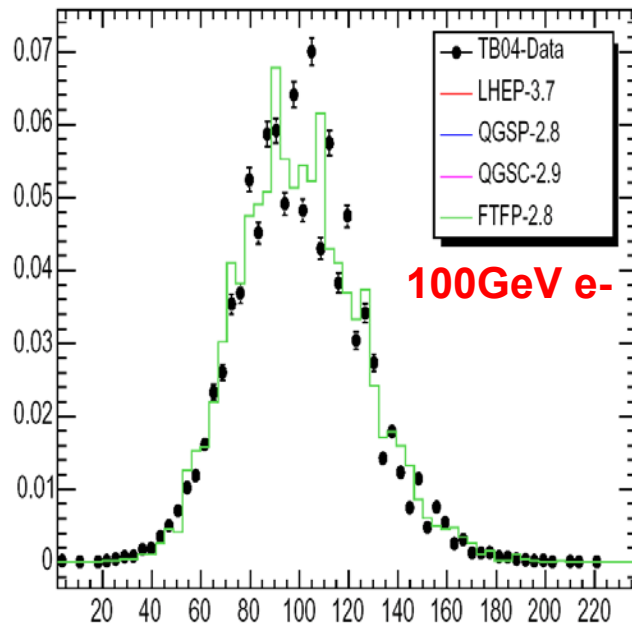
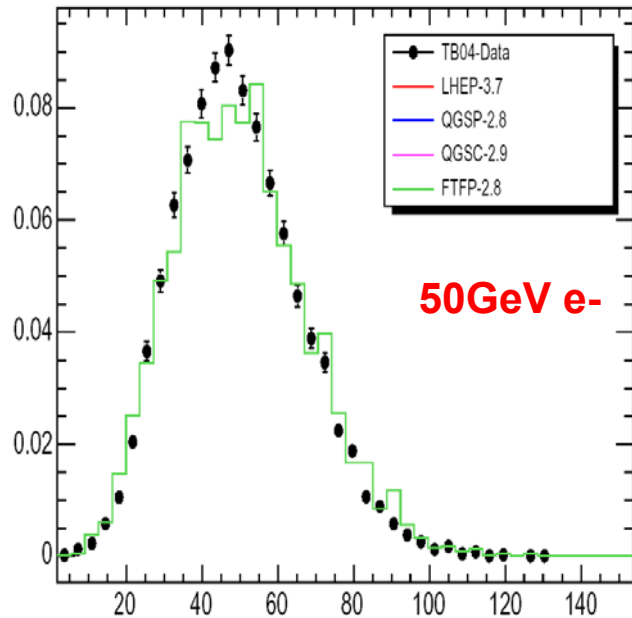
standalone Geant4 with local simulation of Cherenkov light generation, trapping, transportation and PMT quantum efficiency.

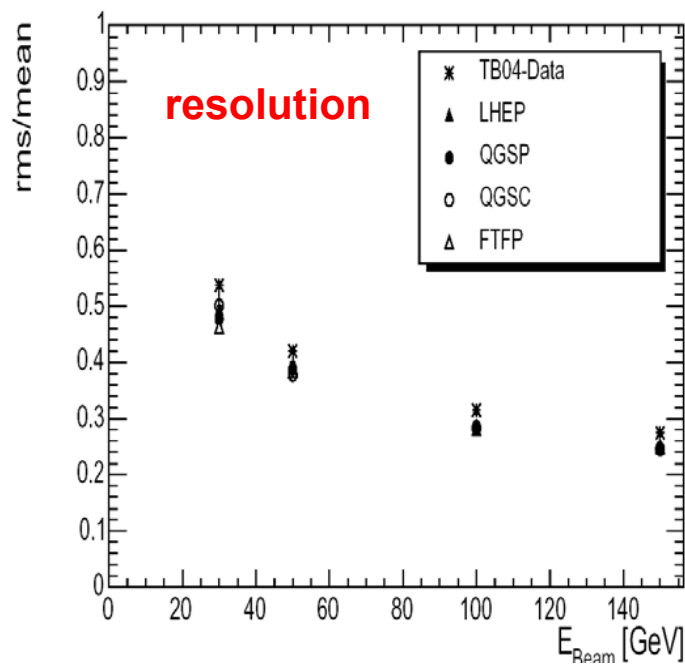
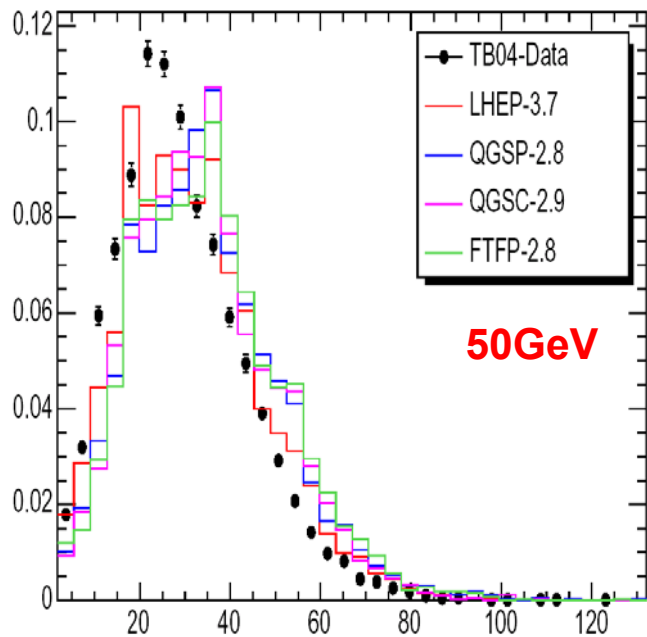


## HF (Long)

### Electrons

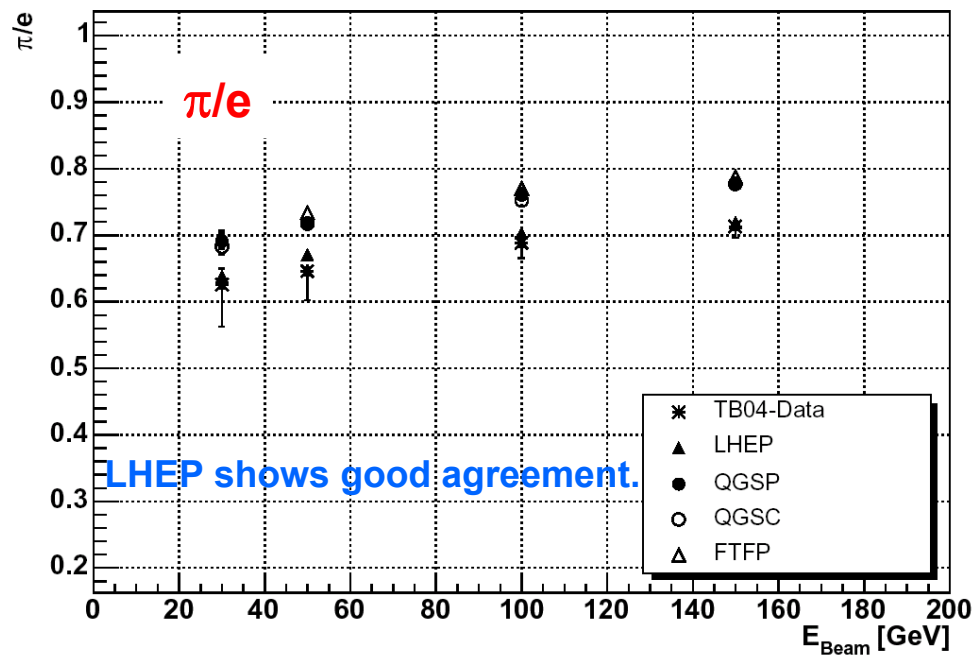
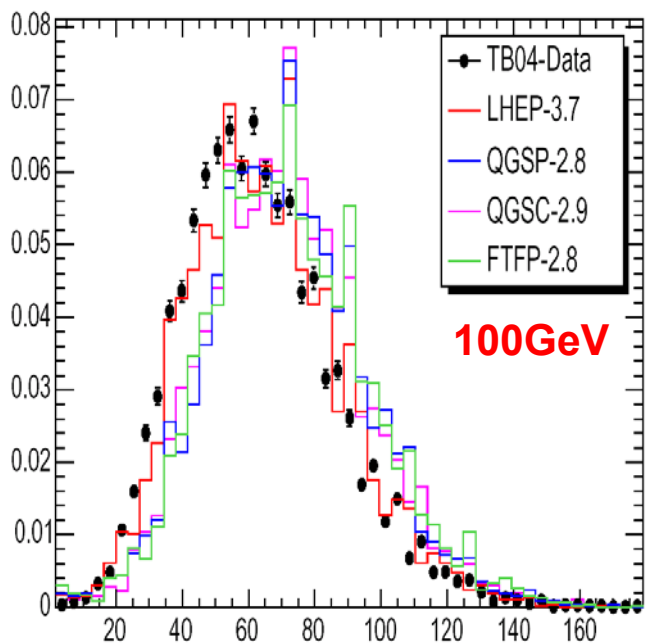
Very detailed simulation with G4 reproduces electron signal very well.





HF (Long)

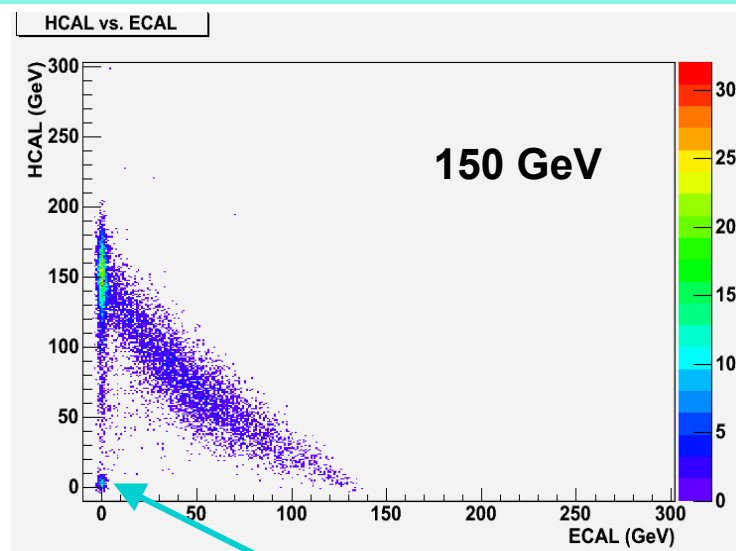
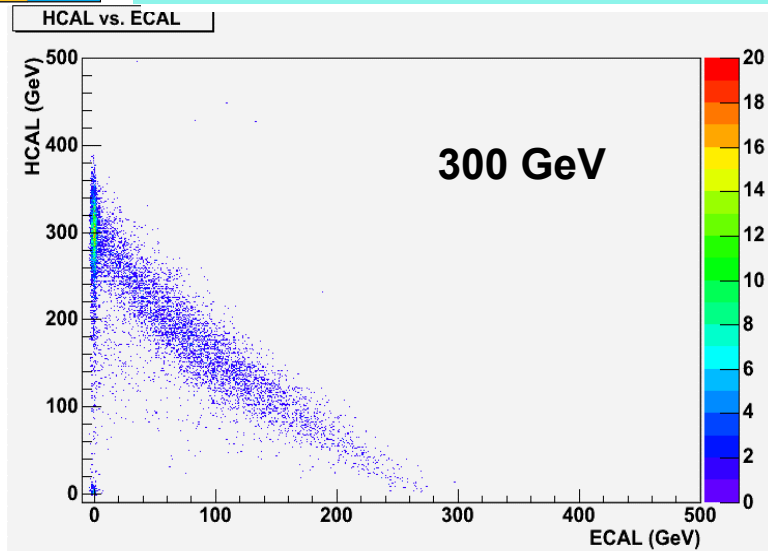
pi-



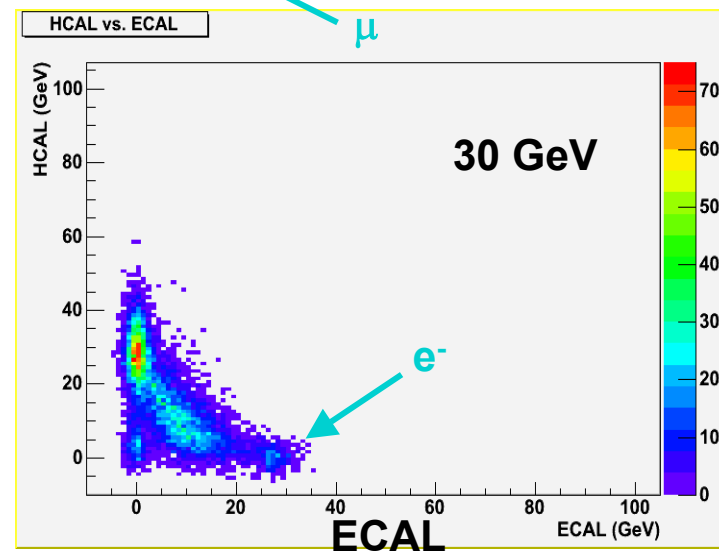
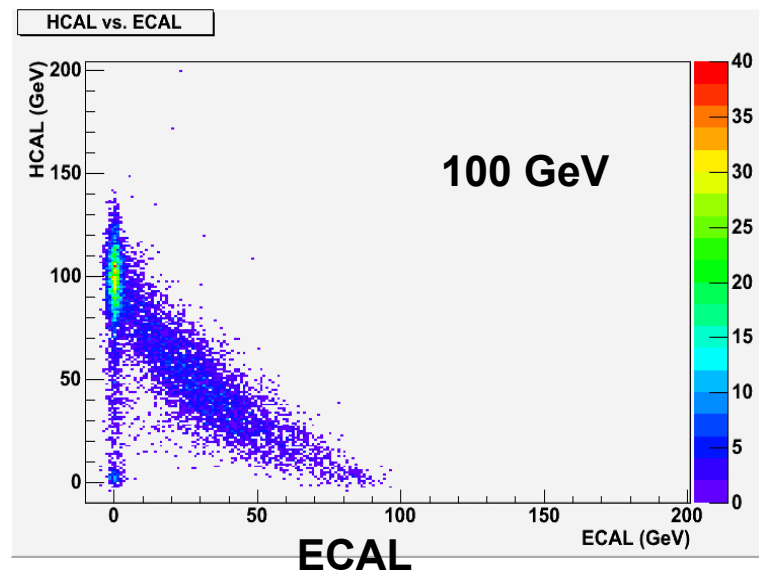


# EC+HB High Energy Data (pi-)

HB



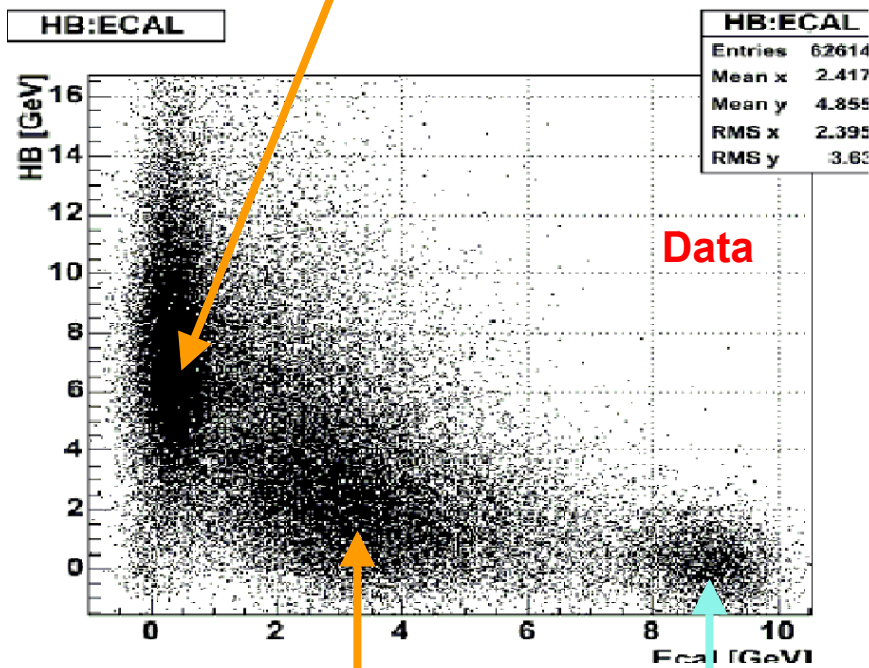
HB





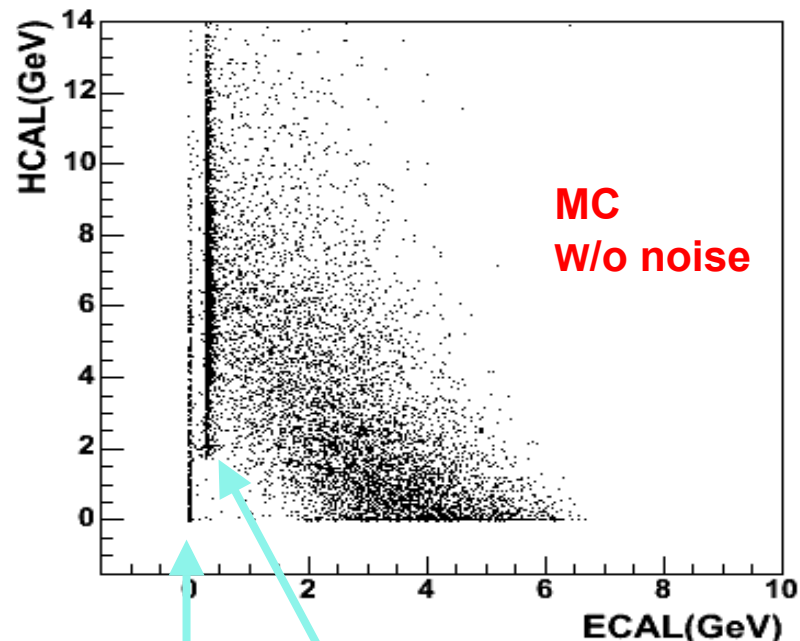
# 9 GeV $\pi^+$ beam

mip in ECAL, i.e. no-interaction in ECAL



Interactions in ECAL

$e^+$



$\pi \rightarrow \mu \nu$  decays in beam line

Interactions in beam line

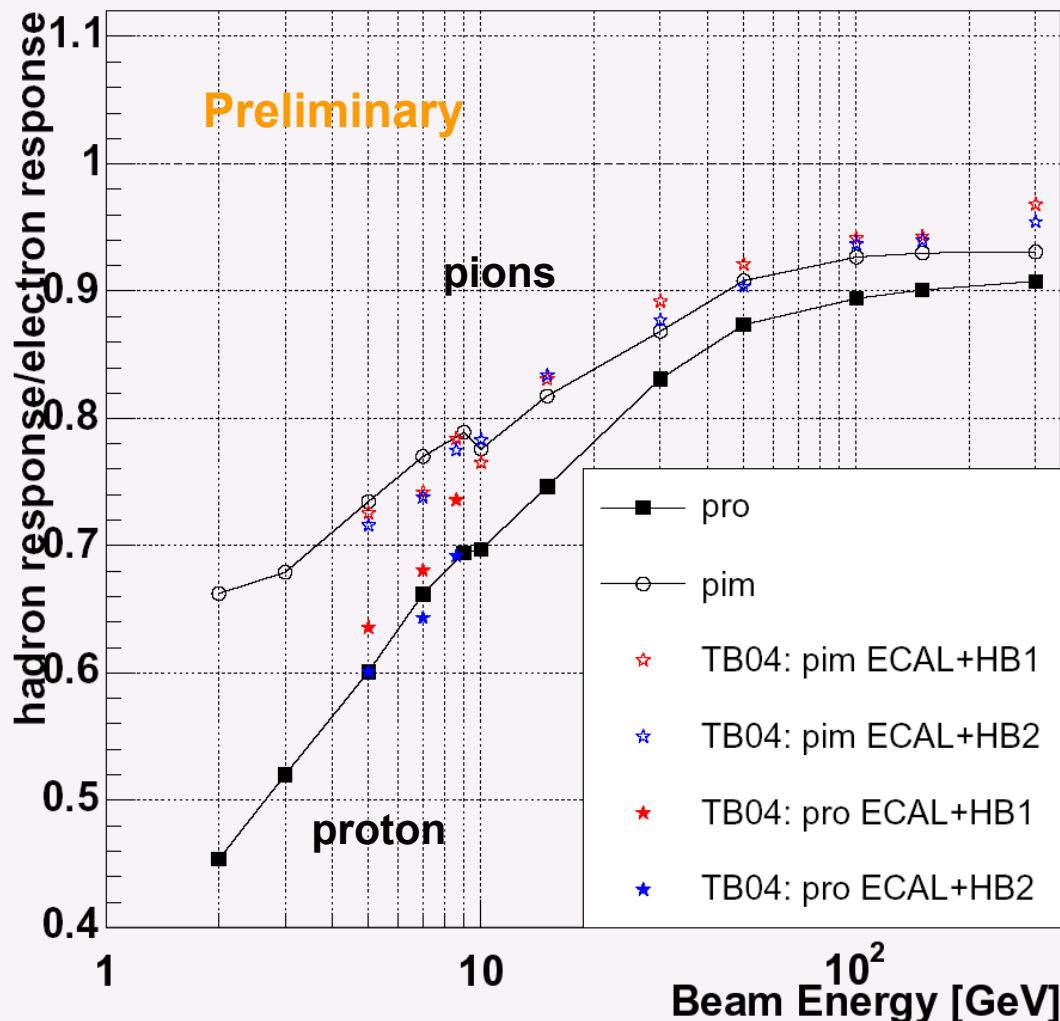
Need a lot of clean-up !



# EC+HB

# $\pi/e$

LHEP  $\pi/e$  (No Birks corr.)



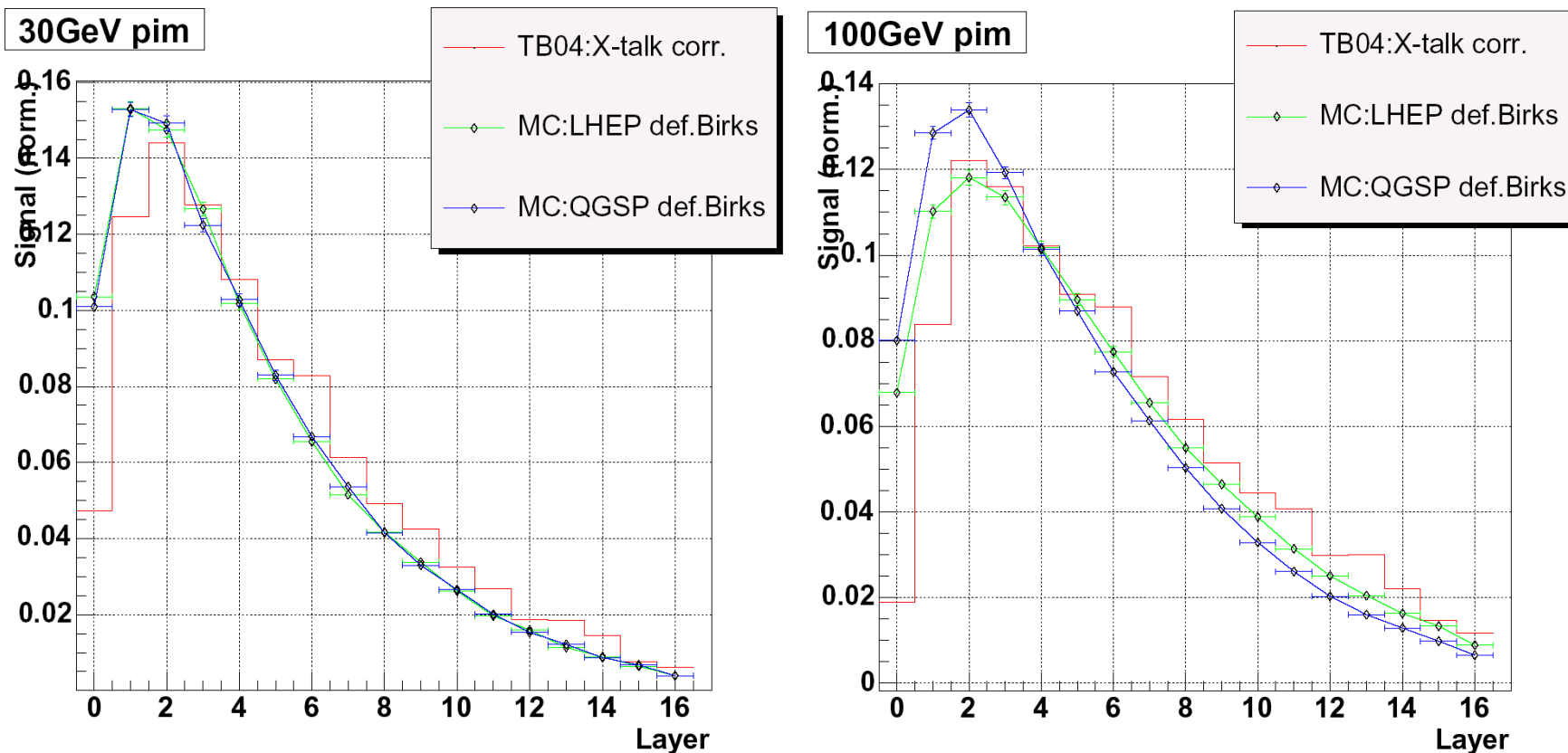
LHEP without scintillation saturation effect (Birks' law) shows a reasonable agreement with data for EC+HB combined system.

Need more beam clean up and better understanding of systematic errors before making more definitive conclusion, especially HB alone data, (not shown today) ...



# Longitudinal Shower Profile

Very preliminary result



Different longitudinal shower profiles by two G4 physics models at high energy.



# TB2006

## Goal

- Measure performance of real CMS calorimeter.
- Obtain better low energy data set.
- Establish very close work relationship with ECAL group in operation of the detector and data analysis.

## Needs:

- Real ECAL modules.
  - HCAL TB02-04 used a 7x7 matrix and PMT readout.
- Improvement for low energy beam data.
  - $e/\pi/K/P$  separation - cerenkov counters + (?)
  - muon tagging- bigger and closer muon tagging stations.
  - Rejection of interactions in the beam line. - less material (?) and tagging station for beam interactions.



# Conclusions

## TB2002-TB2004

- **Very successful program.**
  - We started with a system test of HB and then expanded to HE, HO and HF.
  - We successfully operated calibration system and extracted calibration constants.
    - **Constants were loaded to a prototype HCAL database.**
    - **Other constants were also measured, e.g. ADC-to-GeV, pulse shape, noise level, signal light attenuation, timing, etc.**
  - We obtained good 5-300GeV beam data for validation of GEANT4 physics models – analysis in progress.
- + We operated a prototype remote operation center at Fermilab.

## TB2006 - last testbeam run before LHC starts.

- **Real EB modules with HCAL.**
- **Low energy data with improved beam line setup.**
- + **Obtain final calibration constants.**



**Additional Slides**



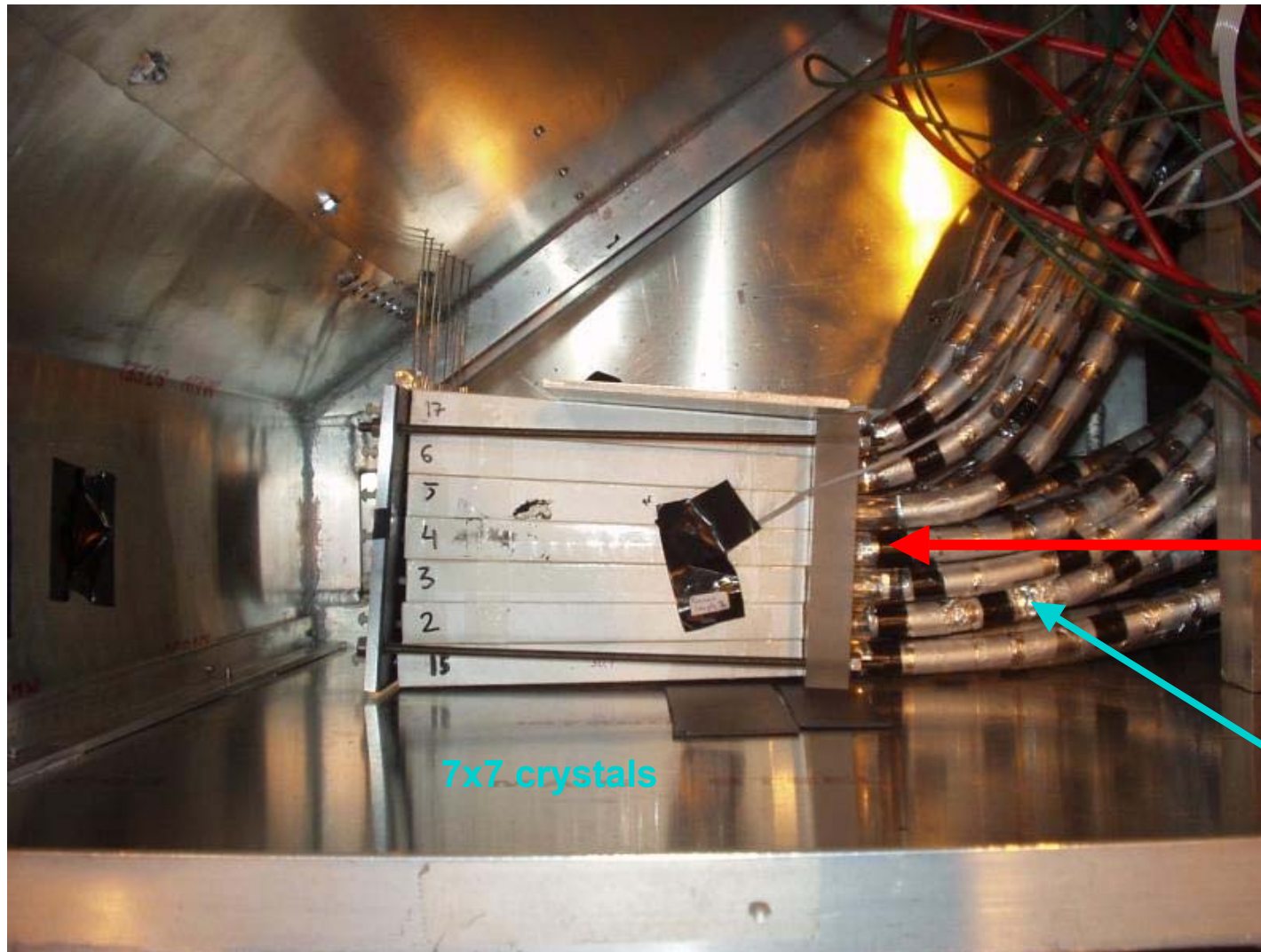
# Summary of TB2004 runs

- **May 17-Jun8 , High energy run**
- Jun 8-14, no beam time install HO
- Jun 14-21 25 ns run time
- Jun 25- Jul 7: first HF run
- Jul 7-14 : 1<sup>st</sup> week of VLE run
- Jul 14- Aug11 : second HF run
- Aug 11- 18: 2<sup>nd</sup> week of VLE run
- Aug 18- Sep 22: other experiments in H2
- Sep 22-Oct 4: HCAL-EMU setup
- Oct 4-11 25ns **HCAL-EMU** run
- **Oct 13-18: 3<sup>rd</sup> week of VLE run**
- **Feb.'05 Wire source calibration run**

**Slice Test**



# ECAL 7x7 matrix



View from top

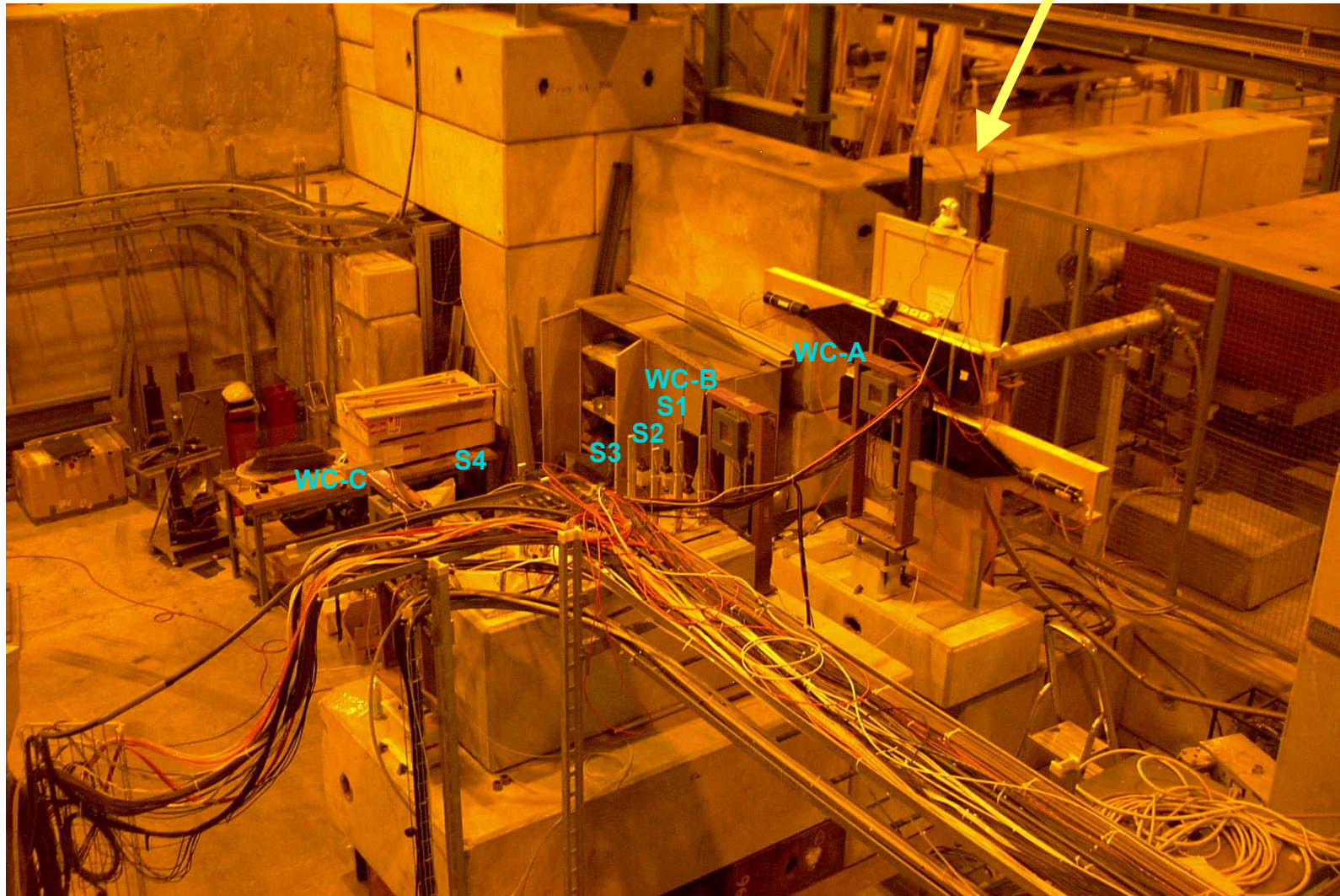
**BEAM**

7x7 crystals

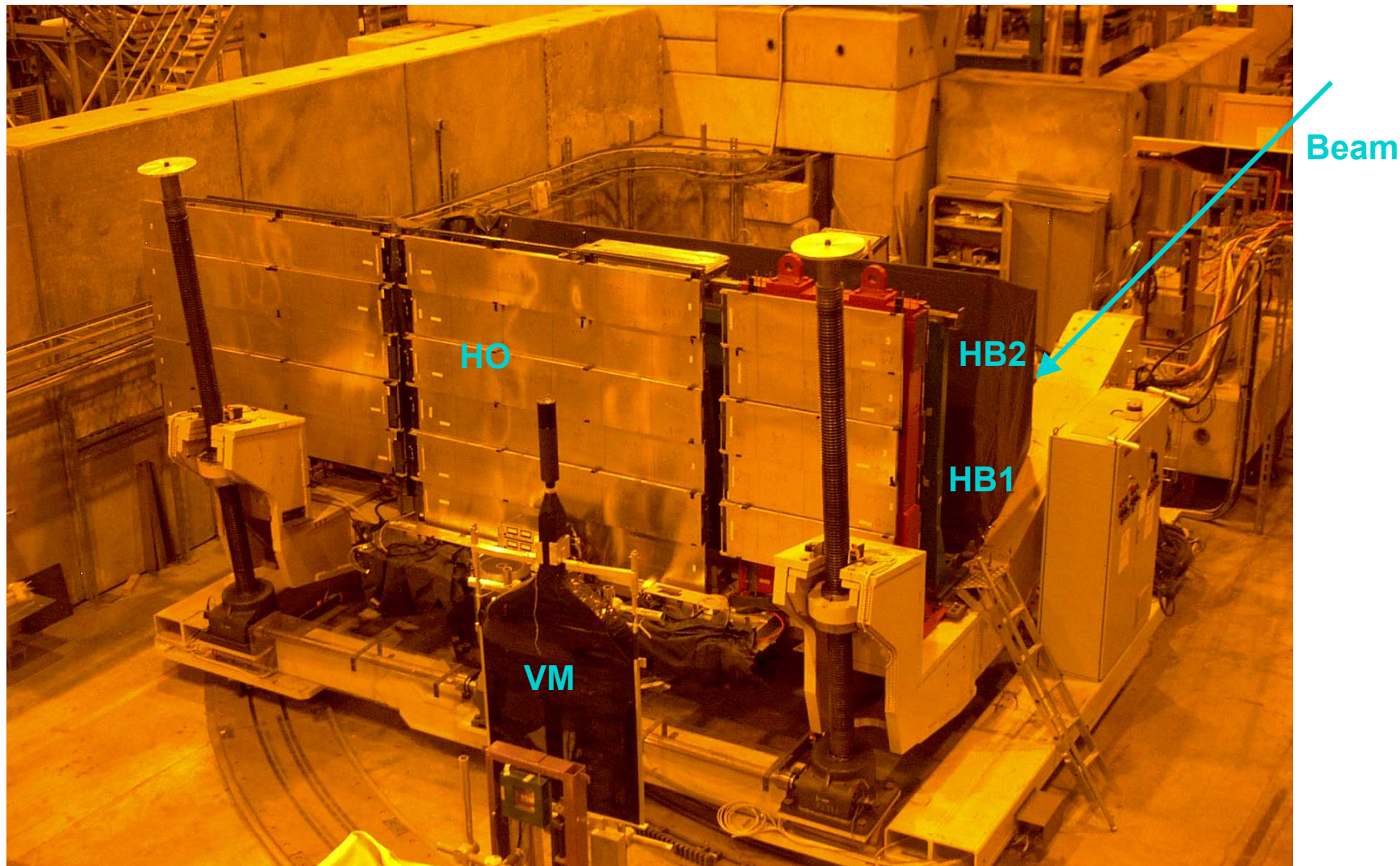
Light guides  
to PMTs



# HCAL Triggering Counters and a webcam



# HO

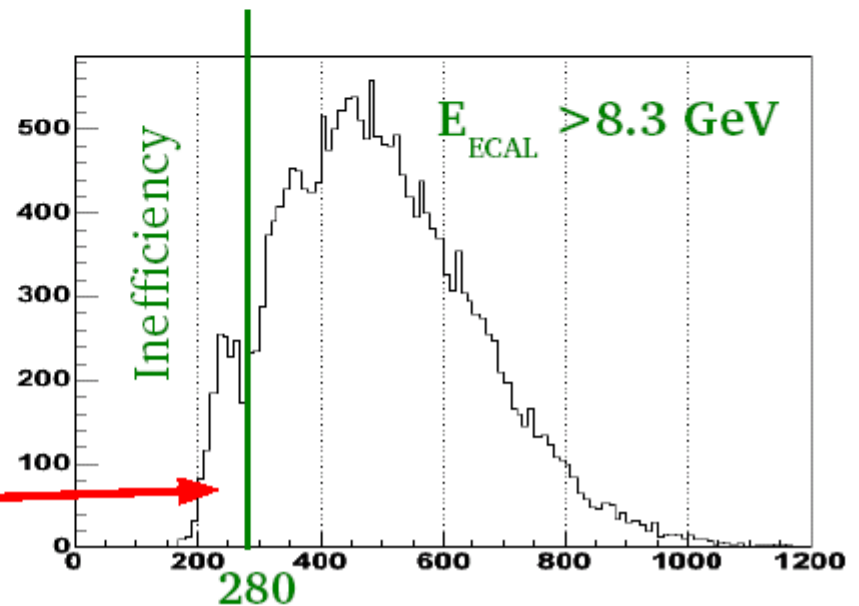
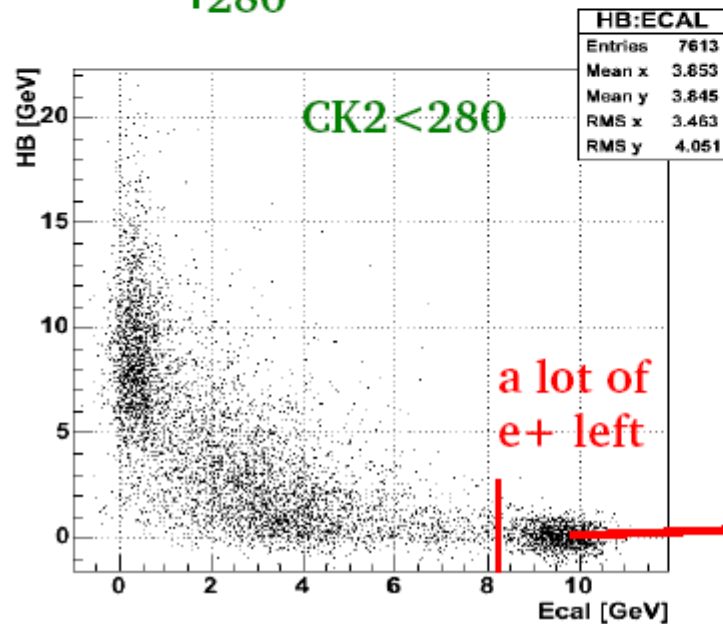
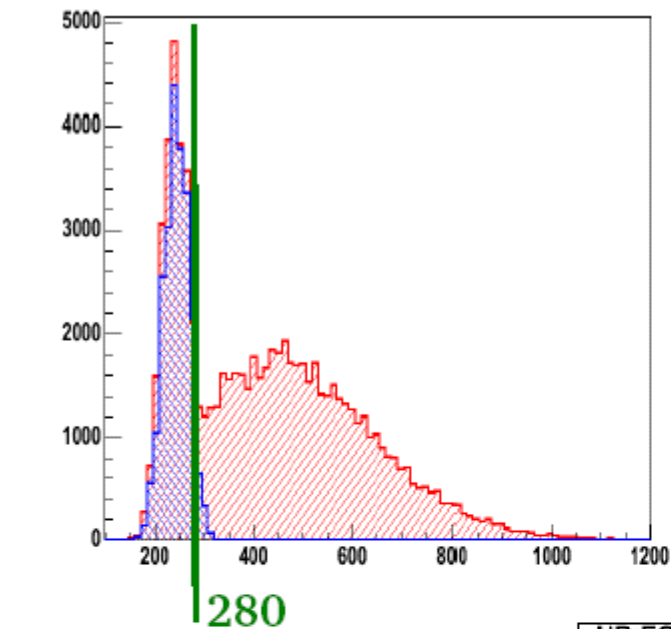


## *P-ID with CK2 (cont.)*

$\pi^+$  10 GeV tune

*CK2 Eff.  $\approx 92\%$*

**Electron identification**

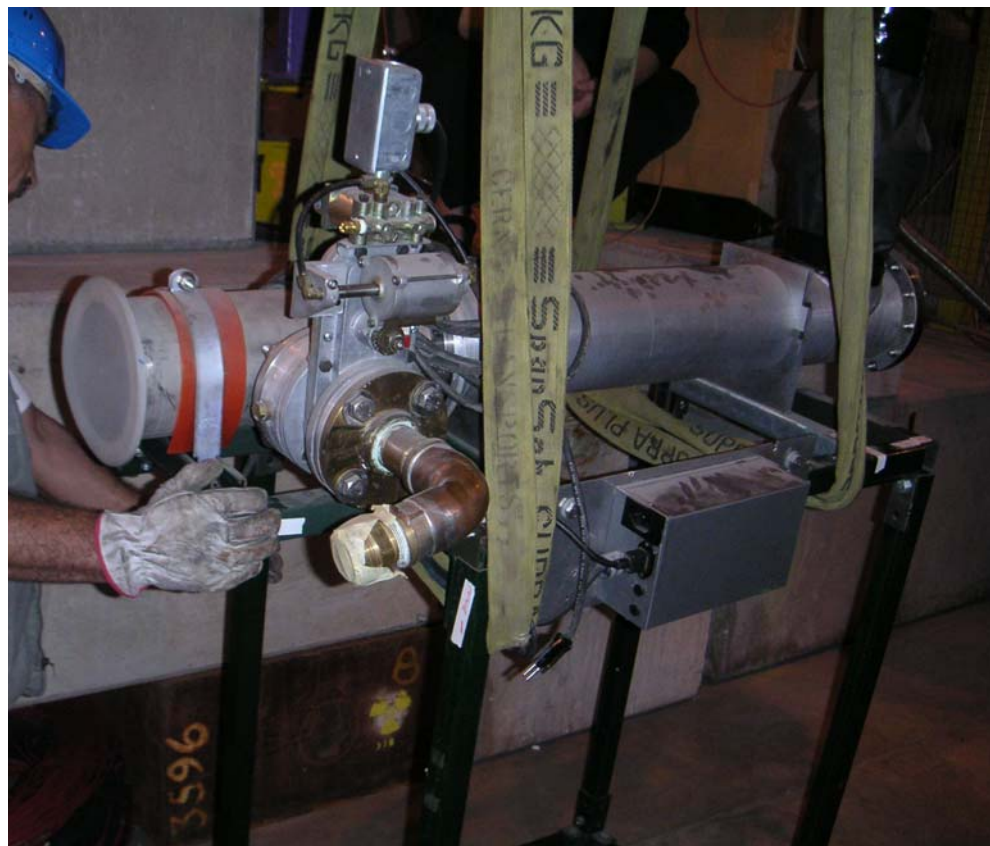




# P-ID with Cerenkov Counter 3 (CK3)

The momentum thresholds  
for the range of  $dn$  are:

$dn$ *E-6	$P(\pi)$	$P(\mu)$	$P(p)$	$P(K)$
2432	2.0	1.51	13.5	
1557	2.5	1.89	16.8	
1082	3.0	2.27	20.2	
<b>795</b>	<b>3.5</b>	<b>2.65</b>	<b>23.5</b>	<b>12.35</b>
609	4.0	3.03	26.9	
481	4.5	3.41	30.3	
390	5.0	3.79	33.6	

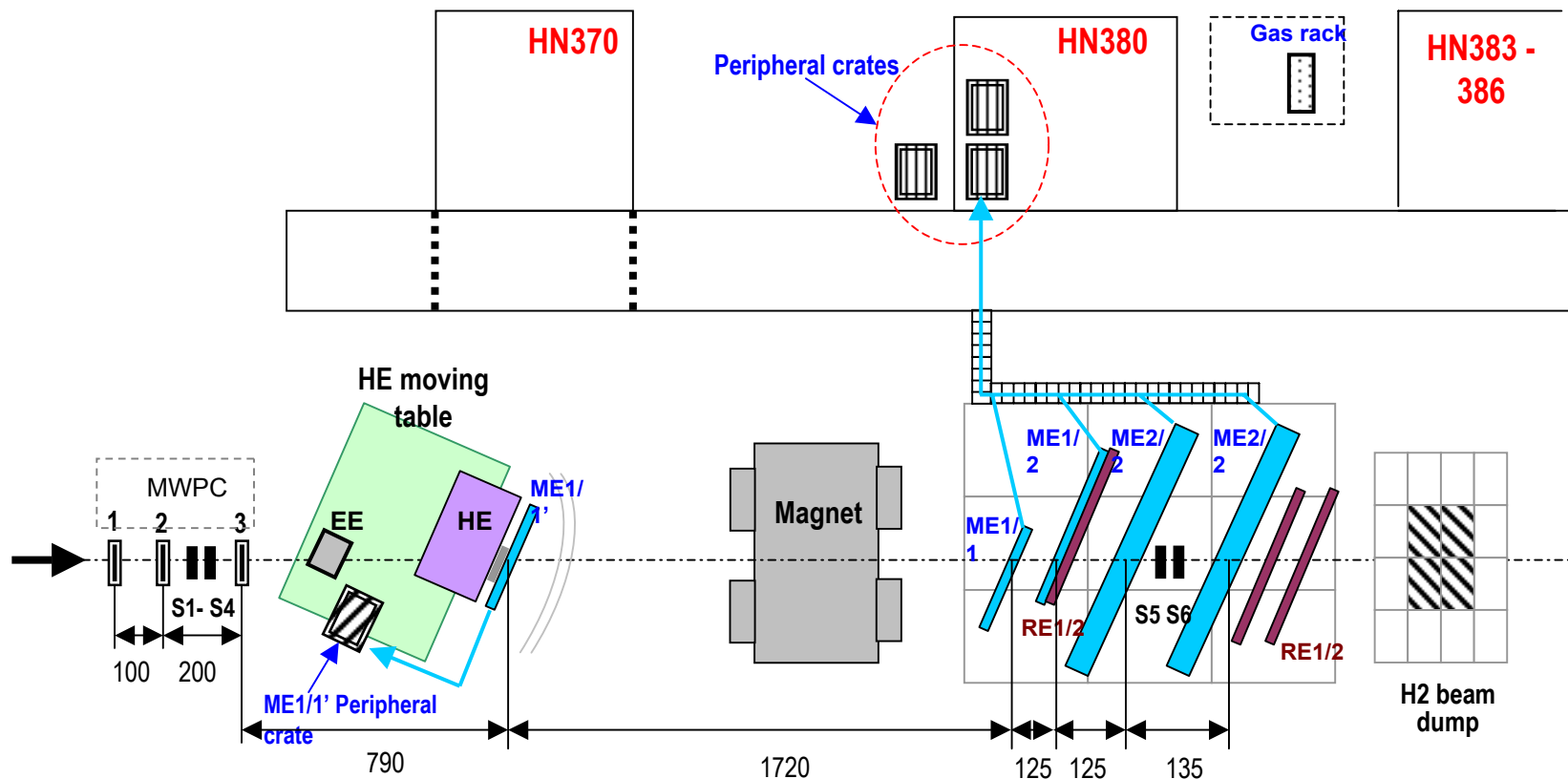


**Freon Cerenkov Counter**



# HE/ME Slice Test at H2

With 25ns beam in Oct.2004



Length of optical links from peripheral crates– 50 m

Counters: S1,S4 – 14 x 14 cm; S2 – 4 x 4 cm; S3 – 2 x 2 cm; S5 – 10 x 10 cm; S6 – 12 x 12 cm